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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No.	LEW 16,682-1
First Inventor or Application Identifier	Chubb, Donald L.
Title	Rare Earth Optical Temperature Sensors
Express Mail Label No.	EJ596690569US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. [X] *Fee Transmittal Form (e.g., PTO/SB/17)
   (Submit an original and a duplicate for fee processing)

2. [X] Specification   [Total Pages [10]]
   (preferred arrangement set forth below)
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings (if filed)
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure

3. [1] Drawing(s) (35 U.S.C. 113)   [Total Sheets [1]]

4. Oath or Declaration   [Total Pages [2]]
   a. [X] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 C.F.R. § 1.63(d))
      (for continuation/divisional with Box 16 completed)
      i. [ ] DELETION OF INVENTOR(S)
         Signed statement attached deleting
         inventor(s) named in the prior application,
         see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

*NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

5. [ ] Microfiche Computer Program (Appendix)

6. Nucleotide and/or Amino Acid Sequence Submission
   (if applicable, all necessary)
   a. [ ] Computer Readable Copy
   b. [ ] Paper Copy (identical to computer copy)
   c. [ ] Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. [X] Assignment Papers (cover sheet & document(s))

8. [ ] 37 C.F.R.§3.73(b) Statement   [X] Power of Attorney
   (when there is an assignee)

9. [ ] English Translation Document (if applicable)

10. [X] Information Disclosure Statement (IDS)/PTO-1449   [X] Copies of IDS Citations

11. [ ] Preliminary Amendment

12. [X] Return Receipt Postcard (MPEP 503)
   (Should be specifically itemized)

13. [ ] *Small Entity Statement(s) (PTO/SB/09-12)   [ ] Statement filed in prior applicat Status still proper and desired

14. [ ] Certified Copy of Priority Document(s)
   (if foreign priority is claimed)

15. [ ] Other: _____
   _____
   _____

16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:
   [ ] Continuation   [ ] Divisional   [ ] Continuation-in-part (CIP)   of prior application No: _____/_____
   Prior application Information: Examiner_____   Group / Art Unit: _____
   For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

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jc574 U.S. PTO
06/01/99

RARE EARTH OPTICAL TEMPERATURE SENSOR

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for Government purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

The present invention relates to temperature sensors and in particular to high temperature optical temperature sensors.

Selective emitters are devices for converting thermal energy into narrow band radiation or energy. Most solid state materials have nearly a constant spectral emittance (gray body). The spectral emittance of a rare earth is characterized by several emission bands in the visible and near infrared region resulting from electronic transitions from the lowest excited states. Materials containing rare earths (e.g., ytterbium (Yb), erbium (Er), thulium (Tm), dysprosium (D_Y), and holmium (Ho)) can emit in narrow wavelength bands in the visible and near infrared region of the spectrum.

Selective emitters have been used in thermophotovoltaic energy conversion systems such as those described in U.S. Patent Nos. 4,584,426 and 5,080,724.

Many existing temperature sensors are unsuitable and/or uneconomical for use in high temperature (greater than 2,000°K) harsh environments. For example, metal thermocouples suffer from high thermal conductivity (e.g., 1 W/cmK) that conducts heat

away from the measurement site, causing errors in the measurement. Other sensors may require sophisticated electronics or other techniques to eliminate errors from the measurements.

SUMMARY OF THE INVENTION

An optical temperature sensor includes an emitter having a selective energy emission band. The emitter emits energy within the emission band in response to the emitter temperature. The sensor also includes a light pipe having a first and a second end. The first end communicates with the emitter. Also included is an optical bandpass filter communicating with the second end. The filter has a pass band corresponding to the emission band. Also included is a detector communicating with the filter. The detector detects the emitted energy as a measure of the temperature.

BRIEF DESCRIPTION OF THE DRAWING

The drawing is a schematic diagram of a sensor according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawing, an optical temperature sensor 10 includes a selective emitter 12, a light pipe 14, an optical bandpass filter 16 and a detector 18. The emitter 12 may be, for example, a section of a circular cylinder friction fit into a cavity in the end of the light pipe 14 and have an approximate longitudinal thickness of 0.1 mm and a diameter in the approximate range of 0.1 to 1 mm. The selective emitter may also be deposited on the end of the light pump by a conventional film deposition technique such

as evaporation, sputtering, or plasma spraying.

The emitter 12 may be composed, for example, of a rare earth oxide, a rare earth alumunum garnet, or a rare earth doped host material. The emitter 12 has a selective energy emission band, i.e., the emitter emits energy within the emission band in

5   response to the temperature of the emitter 12. The host material of the emitter 12 may be, for example, yttrium aluminum garnet (YAG, $Y_3Al_5O_{12}$) or yttrium oxide (Y_2O_3). Different rare earth dopants provide different selective emission bands. For example, Yb provides a band about λ=1 μm, Er: λ=1.5 μm, Tm: λ=1.7 μm, Ho: λ=2.0 μm, and D_Y: λ=2.7 μm.

10   The radiation emitted by the emitter 12 is coupled into the light pipe 14. The light pipe 14 may be, for example, a circular cylindrical optical fiber having an approximate diameter in the range of 0.1 to 1.0 mm. The light pipe 14 acts as a waveguide for the radiation emitted by the emitter 12. The light pipe 14 may be composed, for example, of sapphire, yttrium oxide or quartz. The filter 16 is a

15   conventional optical bandpass filter. The filter 16 passes radiation in the emission band of the emitter 12. Radiation in the light pipe 14 within the emission band of the emitter 12 is passed by the filter 16 to the detector 18. Typically, the detector 18 will be an optical sensor sensitive to a relatively broad band of radiation (e.g., near infrared, infrared) which will include the emission band of the emitter 12. The detector 18 may

20   be, for example, composed of silicon, lead sulfide (PbS) or indium antimonide (InSb).

The temperature converter 20 receives a signal from the detector 18 indicative of the radiation emitted by the emitter 12 and converts this signal to a more useable form, e.g., a displayed temperature, a digitized temperature, a temperature control signal or an alarm.

25   The radiation in the emittance bands of the rare earths is strongly dependent on the temperature (e.g., greater than T^4). The radiation emitted by a rare earth in an

emission band is as follows:

$$q_E = \frac{15}{\pi^4} \varepsilon_b \sigma_{sb} T^4 \int_{u_l}^{u_u} \frac{u^3}{e^u - 1} du$$

where $u_u = \dfrac{hc_o}{\lambda_u kT}$ and $u_l = \dfrac{hc_o}{\lambda_l kT}$

σ_{sb} = Stefan-Boltzmann constant
λ_u = short wavelength end of selective emitter emission band
λ_l = long wavelength end of selective emitter emission band
h = Planck constant
c_0 = speed of light in a vacuum
k = Boltzmann constant
T = temperature in degrees Kelvin
ε_b = emittance of emission band of selective emitter

If the radiation then travels through the light pipe 14 and the filter 16 (which passes wavelengths between λ_l and λ_u), the radiation at the detector 18 will be:

$$q_d = T_f T_s q_E$$

T_f = transmission of filter
T_s = transmission of light pipe

The radiation q_E leaving the emitter 12 is a sensitive function of the temperature T of the emitter 12. Therefore, excellent temperature resolution is possible with the sensor 10. In addition, the host materials YAG and yttrium oxide, or a rare earth oxide, or a rare earth aluminum garnet, can be used in high temperature (greater than 2,000°K) environments, thus providing a sensitive temperature sensor that can operate in high temperatures and harsh environments.

The most expensive component in the sensor 10 is the detector 18. As a result, the lowest cost sensor 10 will use a detector of silicon. In this case, a Yb selective emitter may be chosen because such an emitter has an emission band centered at about $\lambda=1$ μm and silicon responds only for λ less than 1.1 μm (near infrared). The emitter 12

5   may then be, for example, ytterbium doped YAG or yttrium oxide.

Using a light pipe 14 of sapphire, the sensor 10 has, for example, a conductivity of about 0.01 W/cmK. This is much lower than that of a metal thermocouple (e.g., 1 W/cmK) and produces much less error in the measurement due to conduction of heat away from the measurement site.

10   Ytterbium, which has the shortest wave length emission band of the rare earths, requires the highest temperature to produce significant radiation. Therefore, if lower temperature operation is required, other rare earths with longer wavelength emission bands may be required. In this case, another detector instead of silicon would likely be chosen.

15   In operation, the emitter 12 is placed in contact with a sample whose temperature is desired. The emitter 12 assumes the temperature of the sample and emits a corresponding amount of radiation within the selective emission band of emitter 12. The radiation travels along the light pipe 14 and through the filter 16 and is detected by the detector 18. The detector 18 provides a signal that corresponds to the temperature

20   of the sample. This signal is converted by the temperature converter 20 into an actual temperature. This conversion can be, for example, a look-up table or a model of the physical relationships.

Temperature error with the sensor 10 will result from stray radiation within the wavelength range transmitted by the filter .16. This error will be small since, for

25   example, sapphire is transparent out to a wavelength of almost 5 μm. Therefore, most of the radiation with a wavelength less than 5 μm that strikes the sapphire will pass

through the fiber and will not reach the detector. Also, the radiation from the emitter 12 will be much larger than any stray radiation within the selective energy emission band. The selective emitter/filter combination has the effect of substantially improving the signal to noise ratio in the sensor.

5   The upper temperature limit for the sensor is determined by the melting point of the emitter material and the light pipe material. For YAG, the melting point is 2,200°K; and for the rare earth oxides the melting points are greater than 2200°K. Sapphire has a melting point of 2,345°K. If a higher operating temperature is desired, then yttrium oxide with a melting point of 2,683°K can be used for both the light pipe and emitter

10   host material.

The lower temperature limit for the sensor is determined by the minimum power that the detector 18 can measure. If Yb is the rare earth used in the sensor, then λ_u is approximately 0.9 μm and λ_l is approximately 1.1 μm. Assuming ε_b is 0.5 and T_fT_s is 0.1, then T greater than 625°K will yield q_d greater than 1×10^{-7} W/cm^2. A silicon

15   detector at room temperature of 0.01 cm^2 area will respond to this value of q_d. Therefore, if Yb is used as the rare earth in the selective emitter then a temperature as low as 625°K is detectable.

It should be evident that this disclosure is by way of example and that various changes may be made by adding, modifying or eliminating details without departing from

20   the fair scope of the teaching contained in this disclosure. The invention is therefore not limited to particular details of this disclosure except to the extent that the following claims are necessarily so limited.

WHAT IS CLAIMED IS:

1. An optical temperature sensor, said sensor comprising:

an emitter having a selective energy emission band, said emitter emitting energy within

5   said emission band in response to a temperature of said emitter;

a light pipe having a first end and a second end, said first end communicating with said

emitter;

an optical bandpass filter communicating with said second end, said filter having a pass

band corresponding to said emission band; and

10   a detector communicating with said filter, said detector detecting said emitted energy as a

measure of said temperature.

2. An optical temperature sensor according to claim 1, wherein said emitter

contains a rare earth element.

15

3. An optical temperature sensor according to claim 1, wherein said emitter is

composed of a rare earth oxide.

4. An optical temperature sensor according to claim 1, wherein said emitter is

20   composed of a rare earth aluminum garnet.

5. An optical temperature sensor according to claim 1, wherein said emitter is a

high temperature host material which is doped with a rare earth element.

25

6. An optical temperature sensor according to claim 3, wherein said rare earth

oxide is ytterbium oxide.

7. An optical temperature sensor according to claim 5, wherein said host material is yttrium aluminum garnet which is doped with a rare earth element.

5

8. An optical temperature sensor according to claim 7, wherein said dopant is ytterbium.

9. An optical temperature sensor according to claim 5, wherein said emitter is

10 composed of yttrium oxide doped with ytterbium.

10. An optical temperature sensor according to claim 1, wherein said light pipe is composed of sapphire.

15 11. An optical temperature sensor according to claim 1, wherein said light pipe is composed of yttrium oxide.

12. An optical temperature sensor according to claim 1, wherein said light pipe is composed of quartz.

20

13. An optical temperature sensor according to claim 1, wherein said detector is a silicon detector.

14. An optical temperature sensor according to claim 1, wherein said detector is

25 a lead sulfide detector.

15. An optical temperature sensor according to claim 1, wherein said detector is an indium antimonide detector.

16. An optical temperature sensor according to claim 1, wherein said sensor

5   operates at temperatures above 2,000°K.

17. An optical temperature sensor according to claim 1, wherein said sensor operates at temperatures between 625°K and 2683°K.

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ABSTRACT OF THE DISCLOSURE

A rare earth optical temperature sensor is disclosed for measuring high temperatures. Optical temperature sensors exist that channel emissions from a sensor to a detector using a light pipe. The invention uses a rare earth emitter to transform the sensed thermal energy into a narrow band width optical signal that travels to a detector using a light pipe. An optical bandpass filter at the detector removes any noise signal outside of the band width of the signal from the emitter.

TEMPERATURE CONVERTER

20

12

14

16

18

10

NASA
National Aeronautics and Space Administration
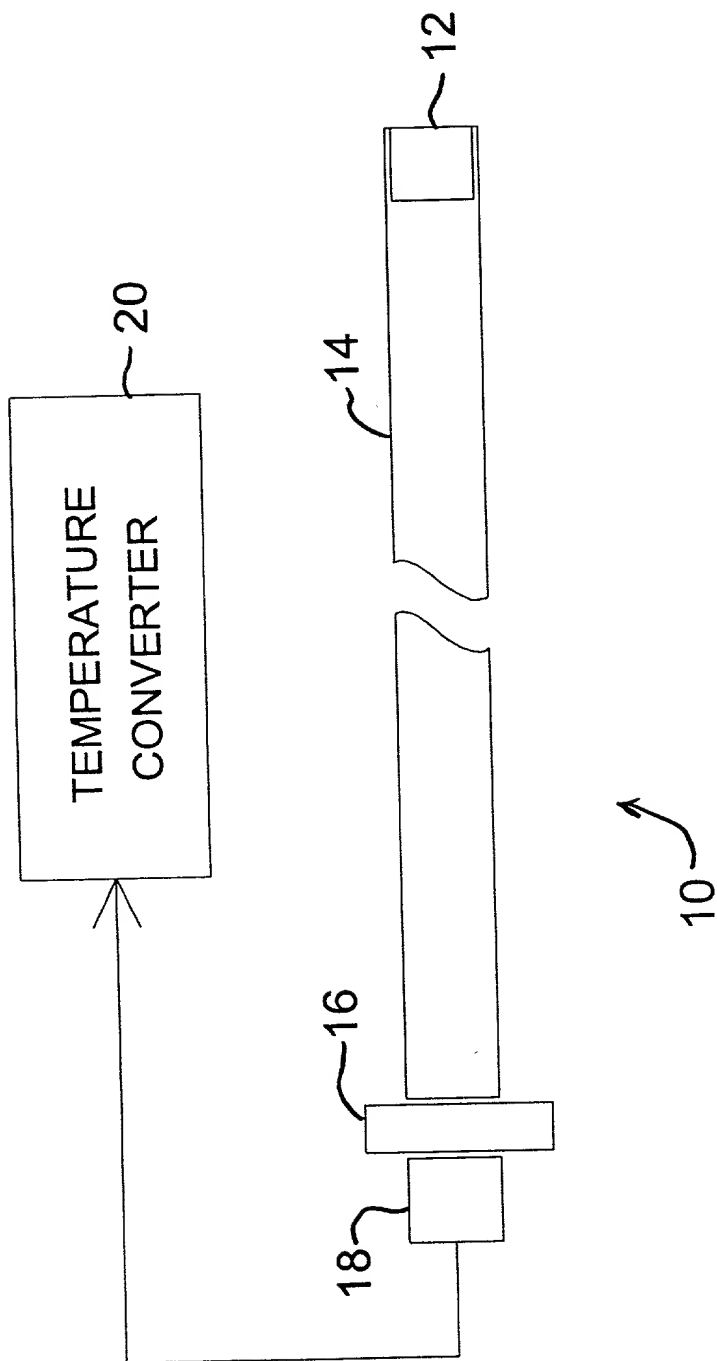
Declaration, Power of Attorney and Petition
Original Application

LEW 16,682-1
(NASA Case No.)

As a below named inventor, I hereby declare that: my residence, post office address and citizenship, are stated below next to my name, I believe I am the original, first and sole inventor *(if only one name is listed below)* or an original, first and joint inventor *(if plural names are listed below)* of the subject matter which is claimed and for which a patent

is sought on the invention entitled ___Rare Earth Optical Temperature Sensor___

the specification, of which ☒ is attached hereto, ☐ was filed on *(Date)* _____ as

Application Serial No. _____ and was amended on *(Date)* _____.

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the Patent and Trademark Office all information which is known to me to be material to patentability as defined in 37 CFR §1.56.

I hereby claim the benefit under 35 U.S.C. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of 35 U.S.C. §112, I acknowledge the duty to disclose to the Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this

application: _____ , _____ , the status of which is
       (Serial No.)   *(Filing Date)*

☐ patented, ☐ pending, ☐ abandoned.

POWER OF ATTORNEY: I hereby appoint the following attorney(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

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June, 1999.
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Further, as a named inventor I certify that the Government of the United States of America, as represented by the Administrator of the National Aeronautics and Space Administration, has [X] as assignment in, or [ ] license to the invention set forth in this application and has the irrevocable right to prosecute this application and to received the patent.

Wherefore, I pray that Letters Patent be granted to me for this invention or discovery described and claimed in the foregoing specification and claims, and I hereby subscribe my name to the foregoing specification, claims, power of attorney and this petition.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001; and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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